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Investigation of agricultural and animal wastes in Greece and their allocation to potential application for energy production ☆

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Abstract

Agricultural and animal wastes constitute a high proportion of biomass in Greece, and are able to play an important role towards the satisfaction of heat and/or energy and related material supply, with respect to the environmental protection targets. This paper describes pyrolysis, gasification and combustion, as a potential agricultural and animal waste exploitation method, and presents a comparison between those treatments when utilized as a source for renewable energy. The aim of the present work was to strengthen the interest in agricultural and animal waste potential for energy production in Greece, through a methodology for the feasibility of utilization of those kinds of wastes as renewable energy resources.

A combination of technical, economic and environmental issues is presented here, and focus on the benefits that thermochemical conversion is able to offer, either in investigation or in future technological application for alternative exploitation methods of animal and agricultural wastes.

Keywords: Agricultural; Animal; Wastes; Energy; Environment; Greece

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Contents

1. Introduction

Greece is located in the east side of Mediterranean Sea, covers an area of 131,940 m^2, with a population ranging 10.6 million people and is enjoying a moderate growth through the last decades [1]. Social, economic and industrial development results in a continuously raising energy-consumption demand. Especially, electrical energy consumption shows a rise of 170% through the previous 20 years [2]. It is clear that owing to the limited indigenous conventional energy sources, country is obliged to import almost 70% of its annual energy demand, in forms of fossil fuels like oil, coal and natural gas [1] (Table 1).

The main electricity supplier in Greece is Public Power Corporation (PPC) and according to a latest forecast, annual increase, in electric power consumption, is expected to reach up to 4% by 2005. Following this scenario, country's electricity demand will reach 72 TWh by 2010 [3]. It is clear that if it is to align with the EC Directive 2001/77/EC and reach a 20.1% contribution of renewable fuels to electricity production, an amount of 14 TWh (including hydroelectric activity) must be supplied by exploitation of non-conventional energy sources [3]. Additionally, and under the EC Directive on February 2001, PPC has lost its monopoly in electricity production, suggesting that 35% of power production should be generated from other sources. Laws and national directives have already liberated electricity market, and a considerable interest in electricity generation from renewable energy sources has already arisen [4]. Up to February 2003, 35 applications had been submitted to Regulatory Authority for Energy (RAE) and half of them, with a total capacity of 82 MW, were authorized [3]. From that point of view, energy generation from biomass resources in Greece faces, nowadays, less bureaucracy and financing problems and has shown a stable growth during the last years.

2. Methodology

This research has been based on information about agricultural and animal waste amounts, locality of production, availabilities, physicochemical characteristics, existing

Table 1
Energy production from fossil fuel sources in Greece (2002) [1]

(KTOE)	Reserve	Production	Recovery products	Imports	Ship tank	Exports
Oil	−517	189	134	4127	3111	3815
Natural gas	4	42	—	1755	—	—
Coal	−218	8.914	—	646	—	5

energy conversion technologies, future perspectives and European Community and national legislation directives about biomass treatment in a national level. All the provided information was combined under the below-proposed methodology for identifying, quantifying, characterizing, developing and analyzing waste, provides thereby, the essential data for planning efficient disposal processes and for formulation facilities for efficient disposal and utilization of biomass for energy production [5].

The methodology used for this study involved a bibliographic study according to which a wide variety of documents and records relating to agricultural residues and animal wastes in Greece (manure and by-products) were collected and studied in order to obtain all the background information as well as useful data to enable a further formulation of a theoretical biomass management model on agricultural and animal waste management in Greece. Interviews with supervisors from various agricultural and animal wastes generation facilities in Greece were also collected, such as the Ministry of Central Macedonia, "Pioneer Hi-Bre Hellas S.A." an agriculture seed selling company, "N.Ach.Philippopoulos S.A." a company for design and construction of electromechanical equipments for energy utilization of biomass, and the National Center of Renewable Energy Sources. All the information collected helped in updating the above-mentioned bibliographic information and shaded light on the present status of energy exploitation of biomass in Greece.

3. Energy supply in Greece

Greece's diverse topography and temperate climate, agricultural and animal breeding culture and windy and shiny climate, give the country the opportunity to exploit almost any kind of renewable energy form. Wind and solar energy are already in use not only in distant areas but also in many Greek islands (Crete, Evia, Andros, Samos, Chios, Lesvos, etc.), while there is a history in burning agricultural (or even animal) wastes in some rural areas in order to produce heat mainly for cooking and heating houses or other closed spaces [1]. Connection difficulties with the main energy/electricity supply systems, economy and environmental sensitiveness were, and still remain, the driving force for renewable energy sources (RES) implementation. Additionally, it is a fact that Greek Energy Market depends on fuel imports from Middle East countries (Saudi Arabia, Iran, Libya, Egypt) and Russia, while indigenous conventional energy sources are mainly low-quality lignite deposits (supplied from Northern Greece's deposits in Ptolemais, Amintaio) and some amounts of petroleum (circa 6.400 bbl/day from Prinos area in Aegean Sea, opposite to Thassos island), negligible natural gas and some hydroelectric station activity [6].

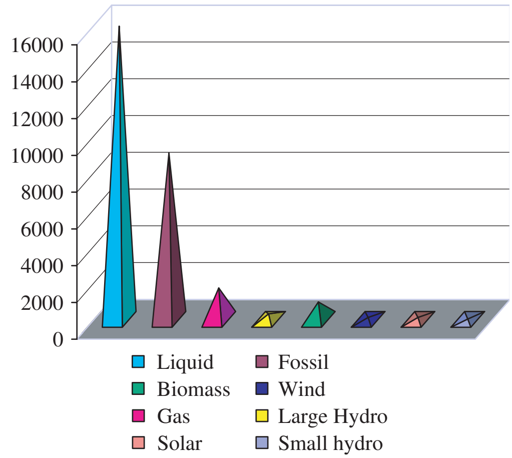


Fig. 1. Contribution of different forms of energy production in Greek Energy Market (KTOE, 2002) [7].

At the moment, biomass contributes only with a small percentage in country's electric energy production (79 GWh according to 2002 estimation), while it traditionally dominates in heat energy production sector, mostly with wood combustion, ranging in second place after lignite exploitation [7]. Lately, there is a significant political promotion (through financial incentives, e.g. tax breakages and public capital subsidies reaching 40%) towards RES utilization [4]. According to information from National Centre of Energy Sources, RES contributed, during 2002, 1.396 KTOE to the total primary energy supply, while the contribution of all other forms of fuels (renewable and fossil) is depicted in Fig. 1. It had already been reported that approximately 2730 plants operated using biomass (cotton gin factories, olive kernel factories, wood processing industries, rice straw mills, etc.) without taking into consideration the biomass amounts that are utilized in house [4].

Additionally, huge amounts of agricultural residues (branches, leaves, kernels, stalks, cuttings, straw, etc.) and animal manures are seasonally accumulated in small areas, leaving a promising source of energy unexploited [8,9]. Only a small percentage of those wastes' energy potential is already utilized, mainly by conventional combustion [8,10,11]; or mixed combustion of agricultural and animal wastes [12,13] or agricultural wastes with coal [14]. Also, some others use anaerobic digestion or co-digestion [15–18] and composting [19,20] of animal and/or agricultural wastes, but those methods are classified as biological. Agricultural and animal waste utilization for energy production purposes could be important not only for economical but also for environmental reasons. Under this perspective, and the fact that thermochemical treatment of agricultural wastes has a long history in Mediterranean region, much effort has been made in scientific research around the world and also in Mediterranean region [17,21–29,34,37,39,40], while scientific research towards animal wastes begins recently to gain a special interest [9,13,21,31–33].

Greece has already made a very promising step towards R&D [22,29], funding and legislation in order to achieve its environmental protection targets with energy satisfaction and air pollution prevention demand. In that way, it is viable for Greece to take advantage of its indigenous vast biomass amounts and produce renewable energy, exploiting almost all forms of RES [4] (Fig. 2).

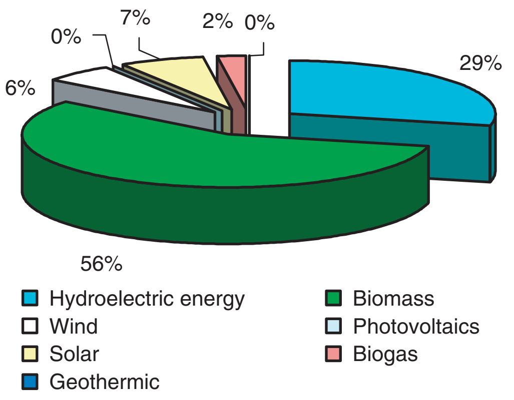


Fig. 2. Energy production from all forms of Renewable Energy Sources in Greece (KTOE, 2003) [41].

4. Agricultural wastes in Greece

Agricultural wastes represent a primary energy source in rural areas of Greece and contribute to energy production, mainly with wood combustion. The main production in agricultural wastes, in Greece, comes from agricultural and farming activities in the fields. Agricultural residues, that characterize Greek agriculture activity, are shown in the figure below (Fig. 3):

The main advantages that biomass energy utilization offers, are reduction of CO_2 and SO_2 emissions in atmosphere (Kyoto protocol alignment, 1997), prevention of climate change (Rio UN framework agreement, 1992), avoiding energy dependence on conventional fossil fuel imports, strengthening employment in decentralized regions (islands and/or rural areas) and contribution to green energy production targets. Following the above advantages of biomass utilization, there are also some disadvantages that bring difficulties to biomass energy exploitation: the big raw material volumes; difficulties in collection and transporting from remote rural areas and islands; high moisture contents by unit of produced energy (and as a result, reduced biomass heating value); the seasonal character of its production and the variety in quality even for the same biomass sample. All above factors lead to high investments when biomass is to be exploited by any of the thermochemical methods, but, in case of combustion, it is encouraging that plant depreciation ranges about 1–3 years [8,35]. Also, according to the latest information from National Center of Energy Sources, biomass had been utilized mainly in house heating and some industrial processes and is generated mainly by combustion, while until the end of 2004 had not been utilized in transport sector for biofuel production (Fig. 4). However, two biodiesel production industries have been constructed recently, the first in Kilkis (ELVI S.A.) and the second in Volos (ELIN S.A.), in order to help the Greece's alignment with European Community's 2003/30/EC directive about biodiesel production and contribution in transport sector.

One of the criteria that is of primary interest when it is to evaluate a method for agricultural waste treatment is the raw material moisture content and the stoichiometric relationship C/N. For moisture contents lower than 50%w/w and ratios C/N > 30, thermochemical treatment of biomass is applicable in the form of direct combustion,

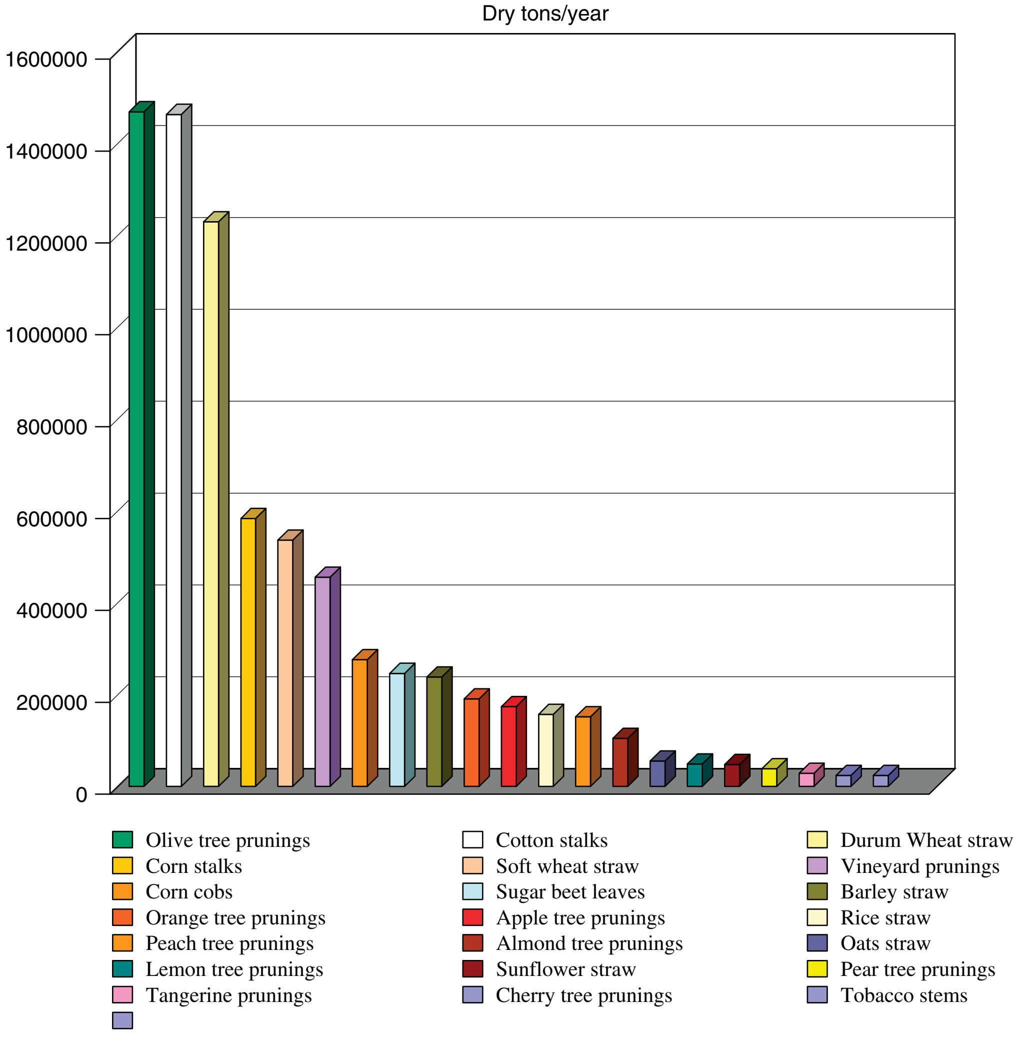


Fig. 3. Basic agricultural wastes in Greece (Dry tons/yr) [7].

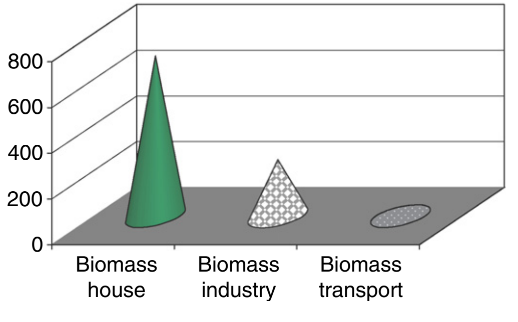


Fig. 4. Biomass use in different activities in Greece (KTOE, 2003) [41].

pyrolysis, or gasification, otherwise it is better to be lead to biochemical treatment (aerobic/anaerobic digestion, composting, etc) [6]. Physical and chemical characteristics of the above-mentioned agricultural residues are shown in the table below, as well as the equal petroleum amount in case of their exploitation for production of renewable energy (Table 2). The areas where agricultural wastes are mainly produced in vast amounts are Thessaly, East Macedonia, Peloponnesus and Crete island [7].

5. Animal wastes in Greece

In Greece, animals produce a substantial amount of wastes, as animal breeding activity is highly developed. The number of animals that were breaded in year 2000 is depicted in Fig. 5. After a rough estimation, it is underlined that due to intensive animal farming, 4550 m^3 of pig, cattle and poultry manures are produced daily, resulting in that way to an annual load of 16.610.000 m^3 of animal manure stock (Fig. 6). Those animal wastes spreading in Greek rural areas come mainly from medium- and large-scale animal farms and are placed all over the country. Also, the fact that there are, traditionally, many small-scale animal farms in Greek rural areas must not be ignored, and as it shows, most of them are located in Central Macedonia (Thessaloniki, Imathia), Epirus (Ioannina), Thessaly (Evia), and Attica representing a 55.6% of the total national amount in animal wastes production [7].

According to the new EU Regulation (1/5/2003), stricter conditions on safe collection, transport, storage, handling, processing, use and disposal of animal by-products are imposed. It is, additionally, known that animal manure and waste contain large amount of pathogen organisms, and is a source of problems like odour emissions, wastewater pollution and vector attraction. As a result, they should be treated with special care as an obligation against public health protection and general environmental protection. Salmonella and Campylobacter are well known to be responsible for chicken meat and manure infections, while *Escherichia coli* becomes more resistant due to antibiotics that are fed to cattle and pigs. It is then clear that heating processes are more effective in killing those pathogens than in deep stacking or fermentation [43,44].

Additionally, with anaerobic digestion, the feasibility of exploiting those wastes would be viable only in medium/large-scale animal breeding units, where waste production would be significant and centralized. Total methane production of those wastes could reach 500,000 m^3/day with an energy potential of 400 TOE [7]. Physical and chemical characteristics of representative animal wastes in Greece are shown in Table 3. Recently, Directive 1774/2002 EC, European Union, imposes a new practice in animal waste treatment, by which animal wastes (meat and bone meal) are prohibited to be fed in animal breeding chain, when those animals are to be consumed following the human food chain. As a result, huge amounts of wastes, which previously were used as animal food, remain unexploited and their potential for energy production reasons could be, now on, under consideration.

6. Thermochemical treatment

Biomass *combustion* [8,10,11] is the most ancient method for energy production that mankind ever used. Even nowadays, combustion contributes to almost 85% in energy production methods. Combustion is characterized by a chemical reaction between a fuel

Table 2
Agricultural residues in Greece and their characteristics [42,8,36,38]

Agricultural wastes	Production (ton/yr)	Availability	Moisture (%)	Ash (%ww)	Volatiles (%ww)	*C* (%ww, dry)	*H* (%ww)	*O* (%ww)	*N* (%ww)	*S* (%ww)	HHV (Kcal/kg)	KTOE
Olive tree prunings	1,468,857	881,314	7.1	4.75		49.9	6	43.4	0.7		4500	396591.3
Cotton stalks	1,463,015	877,809	6	13.3		41.23	5.03	34	2.63	0	3772	331072.5
Durum wheat straw	1,229,189	184,378	40								4278	78882.05
Corn stalks	583,431	350,059	0	6.4		45.53	6.15	41.11	0.78	0.13	4253	148878.1
Soft wheat straw	536,103	80,415	15	13.7	69.8						4278	34403.78
Vineyward prunings	455,589	364,471	40	3.8		47.6	5.6	41.1	1.8	0.08	4011	146189.3
Corn cobs	276,157	165,694	7.1	5.34		46.3	5.6	42.19	0.57	0	4300	71248.42
Sugar beet leaves	246,169	123,084	75	4.8 dry		44.5	5.9	42.8	1.84	0.13	4230	52070.4
Barley straw	238,274	35,741	15	4.9 dry		46.8	5.53	41.9	0.41	0.06	4489	16042.73
Orange tree prunings	190,505	152,404	40	2.8		47	6	43.2	1	0.03	4433	67560.69
Apple tree prunings	173,850	139,080	40								4254	59169.89
Rice straw	157,200	94,320	25	13.4	69.3	41.8	4.63	36.6	0.7	0.08	2900	27352.8
Peach tree prunings	151,729	121,383	40	1	79.1	53	5.9	39.1	0.32	0.05	4500	54622.35
Almond tree prunings	104,902	83,921	40								4398	36906.64
Oats straw	55,383	8307	15	4.9		46	5.91	43.5	1.13	0.015	4321	3589.705
Lemon tree prunings	49,009	39,207	40								4207	16492.72
Sunflower straw	47,671	28,603	40	3		52.9	6.58	35.9	1.38	0.15	4971	14219.72
Pear tree prunings	38,409	30,727	40								4302	13219.31
Tangerine tree prunings	28,580	22,864	40								4207	9617.915
Cherry tree prunings	24,256	19,404	40	1	84.2						5198	10087.11
Tobacco stems	23,767	14,260	85								3848	5487.335
Apricot tree prunings	9829	7864	40	0.2	80.4	51.4	6.29	41.2	0.8	0.1	4971	3909.515

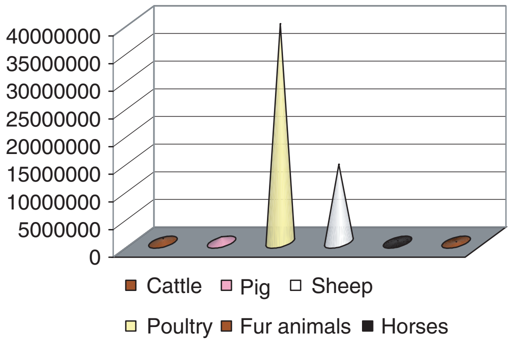


Fig. 5. Number of animals in medium/large-scale Greek farms (2000) [2].

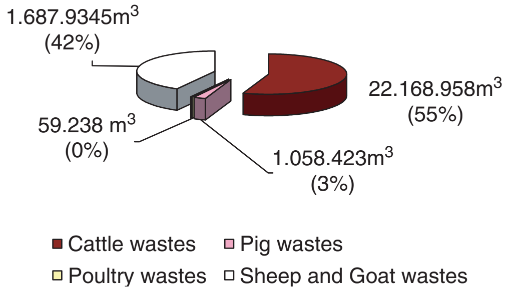


Fig. 6. Animal waste production estimation in Greece (2000) [7].

and usually air in excess levels and produces a significant amount of energy in the form of heat. But it is known that it also contributes unfavourably to environmental pollution through ash generation, gaseous emissions, etc.. Co-combustion of woody wastes with some amounts of fossil fuels promotes renewable source utilization, while it reduces the consumption of fossil fuels, ensures annual feeding of biomass–fossil fuel blend and may lead to money and energy saving.

On the other hand, *pyrolysis* [8,26,27] takes place under high temperature (up to 500 °C), with slow heating rates and under environments with no, in order to prevent biomass combustion. Imposing high temperatures, under oxygen-limited atmosphere, biomass bonds degrade and as a result, a gaseous mixture composed mainly of CO, CH_4 and H_2 is produced. Also, owing to the temperature that is not high enough to break long bonds in carbon chain, tars (bio-oils) are produced in significant quantities. Finally, and after biomass devolatilization, char (black solid residue) is produced. Recent scientific research activities are focussed on flash pyrolysis used in biooil production, with the advantages of less gas and char production.

Biomass *gasification* [8,30,46,47,48] can be considered as a form of pyrolysis, which takes place in higher temperatures and produces a mixture of gases with H_2 content ranging 6–6.5%. Its scope is to optimize and maximize gas production. Firstly, drying and pyrolysis take place, while in second stage, synthesis gas is produced. The reason is that CO and H_2O from combustion are converted to CO and H_2. When imposing high temperatures, biomass bonds break down and reform a mixture of permanent gases

Table 3
Main animal wastes in Greece and their characteristics [7,42,8,45,16,31,20]

Animal wastes	Animal (2000)	Manure (m^3/animal*yr)	Volatile solids (m^3/yr)	Total emissions (kg NH_3/yr)	Manure production (2000)	Number (2010)	Emission (kg NH3 / animal*yr)	Average farm size (animal)	Storage (months)	Application to grassland (%)	Application to arable land(%)	CH_4 (Nm3/yr)	Energy potential (TOE)
Cattle < 1 year	156,000	4.17	Cattle	Cattle	650,43	Cattle	Cattle	Cattle	Cattle	Cattle	Cattle	Cattle	Cattle
Cattle 1–2 years	92,000	7.30	106,215	2,346,000	671,600	276,000	25.5	2	2.00	50	50	71,175	155
Cattle > 2 years	92,000		Pig	Pig	—	Pig	Pig	Pig	Pig	Pig	Pig	Pig	Pig
Male/Heifer	37,000	13.04	—	440,300	482,321	157,000	11.9	10	2.00	50	50	1825	—
Dairy Cow	168,000	16.43	Poultry	Poultry	2,759,400	Poultry	Poultry	Poultry	Poultry	Poultry	Poultry	Poultry	Poultry
Other Cow	137,000	14.60	24	43840	2,000,200	16,216,000	0.32	15,520	2	50	50	109,500	255
Pigs < 20 kg	230,000	0.78	Sheep/Goat	Sheep/Goat	179,893	Sheep/Goat	Sheep/Goat	Sheep/Goat	Sheep/Goat	Sheep/Goat	Sheep/Goat	Sheep/Goat	Sheep/Goat
Pigs > 20 kg	549,000	1.56	980	6,533,100	858,793	15,000,000	2.23	53	2	50	50	—	—
Breeding pigs	56,000	3.13	Horse	Horse	175,200	Horse	Horse	Horse	Horse	Horse	Horse	Horse	Horse
Covered sows	71,000	5.21	—	3,137,500	370,214	183,000	12.5	—	—	—	—	—	—
Poultry	39,492,096	0.00	Fur animals	Fur animals	59,238	Fur animals	Fur animals	Fur animals	Fur animals	Fur animals	Fur animals	Fur animals	Fur animals
Sheep/Goat	14,583,000	1.20	—	141,600	17,499,600	60,000	2.36	—	—	—	—	—	—
Horse	251,000	—	—	—	—	—	—	—	—	—	—	—	—
Fur animals	60,000	—	—	—	—	—	—	—	—	—	—	—	—

consisting mainly of H_2, CO, CO_2 and CH_4. The percentages of those gases in the mixture depend on several factors like the type of gasification agent (air, oxygen, steam or mixtures of them), biomass physicochemical nature (moisture, particle size, heating value, etc.). Comparing with air, when steam is introduced to reform CH_4 to H_2 and CO, higher percentage of hydrogen is achieved, and the produced gas has higher heating value. Additionally, gasification in combination with fuel cells, internal combustion engines or gas turbine systems could be extremely attractive for electricity generation and is expected to be an important part of biomass energy production with environmental friendly way.

Generally, as it concerns the *by-products* from different thermochemical treatments, e.g. gasification against combustion gives better limits in CO_2 emissions and it is widely known that CO_2 is considered "neutral" with respect to air pollution problems. It does not increase CO_2 concentration in atmosphere, as the carbon dioxide released from gasification is already the inherent amount that biomass gained from atmosphere with photosynthesis. Gasification under certain practice (Integrated Gasification combined Cycle) gives higher efficiencies (45–50%) than that is usually achieved via combustion (25–35%) [49]. On the other hand, dioxin content that results from animal manure combustion can be avoided under certain and strict control of good combustion conditions (following EC 2000/76 directive demands). And finally pyrolysis can lead to biofuel utilization, with the advantages that a liquid fuel is able to offer (easy storage for short time and easy transport) or char material exploiting as active carbon (Fig. 7).

6.1. Thermochemical treatment of agricultural residues in Greece

Unfortunately, there is no organized practice in agricultural waste management in Greece until today, even if the country's potential towards it is very promising. The most common management practice in Greece is still burning in field and as a result uncontrolled fires spread and atmosphere pollution is seasonally appearing. There are also some agricultural industries that, usually after private initiative and with the help of public taxation intensives, burn their agricultural residues to produce mainly heat, and then recycle it for utilization in their production activities (Table 4). According to National Center of Renewable Energy Sources, estimation of the total amount of agricultural residues' annual exploitation in Greece reaches the amount of 5.5 million tons in field crops [50].

Industries, that exploit energetic potential of their residues are mainly cotton ginning factories that use the produced heat in order to dry cotton and to heat their space, olive kernel oil factories that burn the olive cake to heat their closed spaces, drying processes and provide heat for greenhouse cultivations, wood industries that burn the sawdust for the same reasons, fruit kernel factories that provide themselves part of their necessary production heat supply, rice mills, etc (Fig. 8).

7. Thermochemical treatment of animal wastes in Greece

The main animal waste sources in Greece are manures from pigs, chickens, cattle, sheep, goat and also some horses and fur animals and residues from meat industry processing, e.g. meat trimmings, bones, feathers, etc. What farm owners used to do as exploitation of animal manures, until recently, was to sell them as a fertilizer [2] or simply spread onto agricultural and/or arable land. Another common method of converting these waste

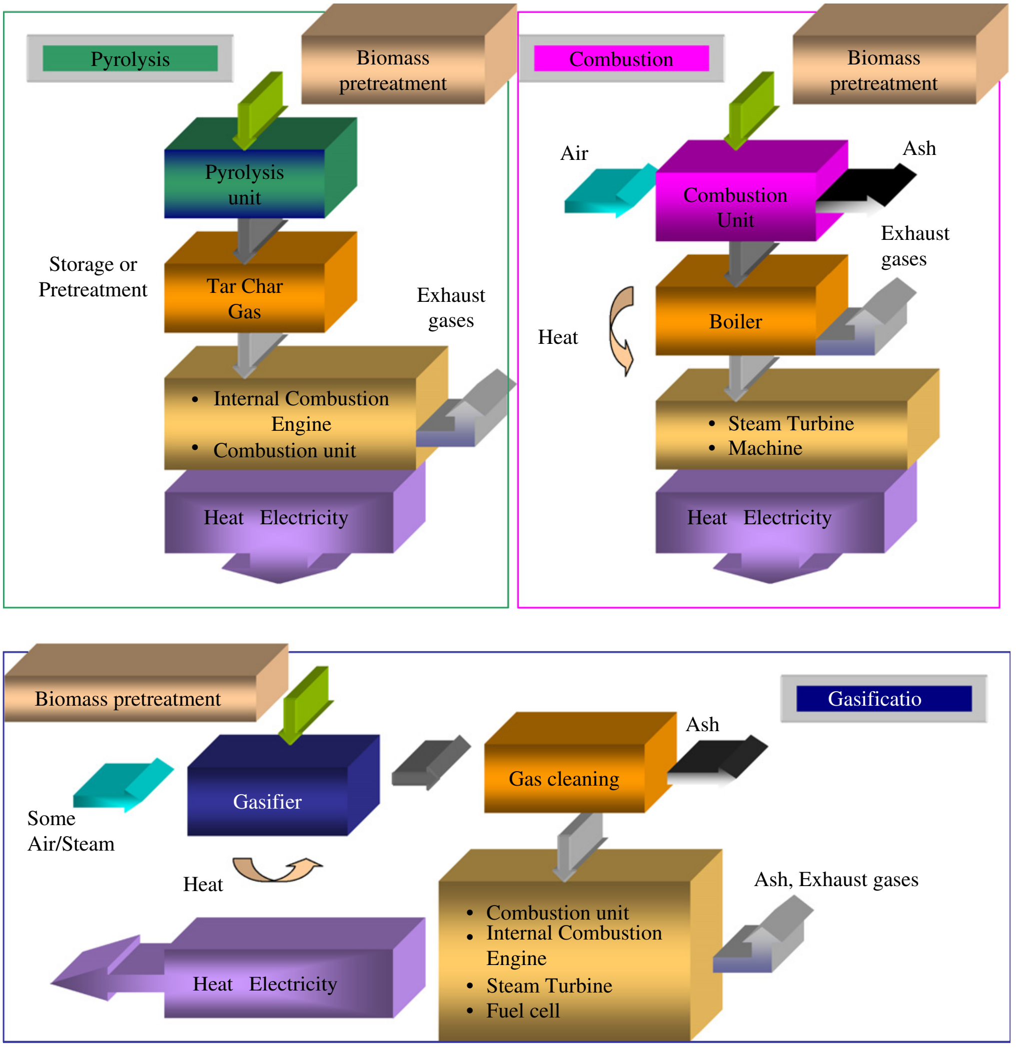


Fig. 7. Agricultural/animal waste thermochemical treatment overview.

materials is via anaerobic digestion [16], a biological treatment that lead to gas production in relatively long periods. Direct product from anaerobic digestion is biogas, rich in CH_4 that can be used in internal combustion engines either, for electricity generation, or burn directly for cooking, and space and water heating. But, at the moment, the most common practice in animal manure treatment in Greece is still their utilization as fertilizer for agriculture land; while in some rural areas, they still combust them for heat production.

7.1. Animal manures in Greece

Animal manures are stocked in rural areas, especially outside medium- and large-scale animal farms, and create significant environmental problems like underground water

Table 4
Plants using agricultural and/or animal wastes for power generation in Greece (2002) [7,3,4]

Industry	Installed electrical capacity (MWe)	Installed thermal capacity (MWth)	Electrical Energy (MWh/y)	Thermal Energy (MWh/y)	Fuel	Technology
Meligalas, Messinia	8.14	n.a.	n.a.	n.a.	Pruning	Gasification, 6 × 1,356 MW engines
Heraclio, Creta	5.42	n.a.	n.a.	n.a.	Olive stones	FBC, Steam turbine
Meligalas, Messinia	5	n.a.	n.a.	n.a.	Olive stones	FBC, Steam turbine
Filipiada, Preveza	4.09	n.a.	n.a.	n.a.	Pig manure	Aerobic digestion
Sparti, Lakonia	3	n.a.	n.a.	n.a.	Fruit peels and fibres	—
Grevena	0.37	n.a.	n.a.	n.a.	Wood residues	Combustion
AGRINO*	0.16	4.3	1033.3	22,611	Rice industry residues	Combustion
Cotton ginning factories (18 units)	n.a			88,889	Cotton residues	Combustion
ALIBRADIS	no	0.141	no	0	Alcohol industry residues	
Tasty foods					Potato residues	
ZANAE					Yeast residues	
Domestic use				8,163,508	Wood	Combustion
Wood residues (58 units)				320,278		
Dry olive kernels (2633 units)				2,325,556	Olive kernels	Combustion
Husk/Kernels				3194		
Rice residues (7 units)				18,333	Rice residues	Combustion
Straw				250		

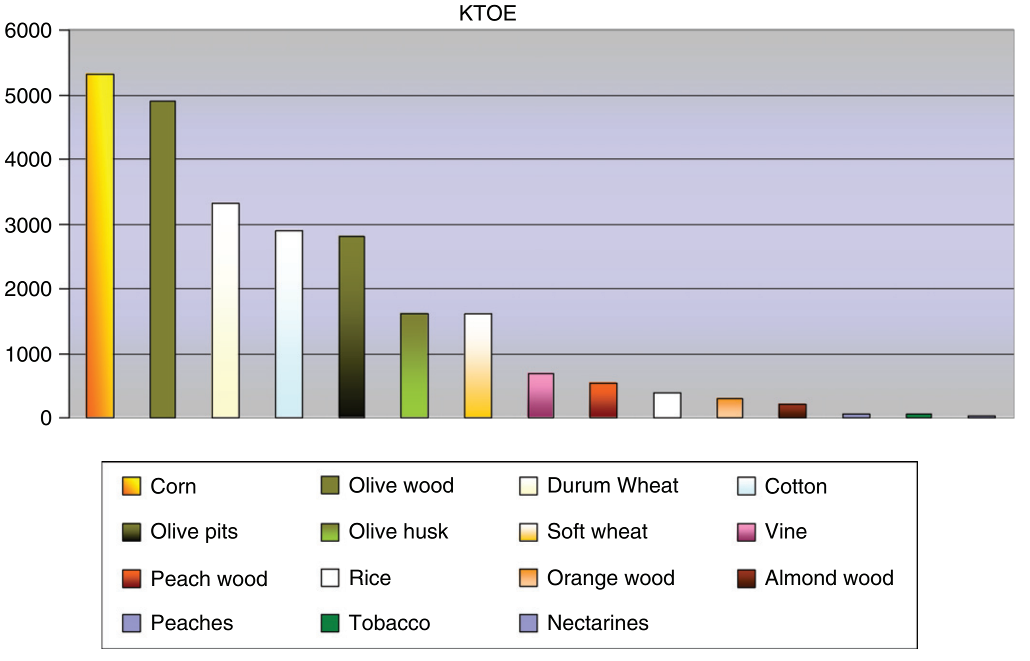


Fig. 8. Energy production from the main agricultural wastes in Greece (2002) [4].

pollution, gas and odour emissions, vector attraction and general visual pollution [43]. The introduction from European Community of even stricter environmental targets on odour and water pollution enforces member states to take into consideration that appropriate waste management is now required, something that would provide further incentive for waste-to-energy conversion.

Above all, the risk of pathogen spreading is still a threat for public health and should not be underestimated. According to animal waste EU Directive (90/667/EEC), there are some rules to prevent of pathogens, if it is to dispose and process animal wastes, and place them on market. According to regulations, animal waste management should be lead in the direction of composting or in a biogas production. As an example, animal by-products used as a raw material in a composting plant must be subjected into the composting reactor to a minimum temperature of 70 °C for 60 min and the resulting compost must reach a standard where Salmonella is absent in a 25 g sample and composted animal by-products may not be spread to pasture land.

As it concerns the animal manures in Greece, the most common practice is spreading them as natural fertilizer in arable land [51], composting in mixtures with indigenous agricultural residues and in some cases combusting them for heat production. The animal manure estimated an annual amount produce to 38,000 tons/day, with a potential production of 1.4 million m^3 of CH_4 and with an energy equivalent of 1.2 MTOE [52].

Thermochemical conversion of animal waste has shown very promising results in treating wastes with safety and in producing oil. It is feasible to successfully convert up to 70% of swine manure solids to oil, and reduce manure chemical oxygen demand up to 75% [9]. Also some attempts have been made in chicken waste energy exploitation, giving very good results in dioxin emission problem [8].

7.2. Animal by-products in Greece

Animal by-products are composed of all the parts of a slaughtered animal that are not destined for human consumption. Meat by-products hide a danger in pathogen dissemination or are assumed as a possible source of illnesses and must also be treated with special care. The most common alternative of their destruction is incineration, while some investigation has been made in order to evaluate their energy content in case of their thermochemical treatment. Even though incineration lies on a reliable technology, an old-existing experience and an effective emission control through state-of-the-art techniques all over the world, there is the negative public perception and competition with new applications that leave it in lower place. In Greece, at present, there are 134 incinerators, which cover all the EU-approved slaughterhouses [53]. But, usually, some amount of meat by-products are utilized in food industries for meat proteins production, in animal food industries and many other applications in product production like cosmetics, pharmaceuticals, etc. Undoubtedly, all uses involve strict heat treatment of at least 20 min, in 133 °C and 3 bar pressure to ensure their safety in utilization. An estimation of animal waste and by-product production in Greece is shown in Table 5, and also the amounts and ways of their present treatment [53].

Main animal by-products are bones, skin and connective tissues (e.g. tendons) meat trimmings, dead farm animals, etc., and according to a new EC Directive (1/5/2003) a stricter management policy is introduced as it concerns their collection, transport, storage, handling, processing, uses and disposal practices. Only 68% of chicken, 62% of pig, 54% of cattle and 52% of sheep and goat is consumed directly, while the rest is turn to be a potential waste and indicates the amounts of animal wastes produced.

Under any circumstances, and especially after the earlier food chain scandals (BSB epidemic, poultry diseases, dioxin crisis, etc.), animal by-products must be treated safely due to their tendency to become a hospitable pathogen carrier [43]. The practice of recycling meat and bone meals to animal feeding is lately prohibited by EC directives, and animal by-products cannot be fed anymore to same species animals. In general, EU requires the same health standards for animal food as those for human food [54,55].

Disposal of specified animal by-products takes place mostly by direct incineration and burial or landfill practice. Additionally, resulting material of animal by-product composting is spread on land as fertilizer. Also, in some countries, they feed dead farm animals to species of animals that do not take part in the human food chain. Only low-risk animal by-products are used as pet food and in pharmaceutical and cosmetic products [54].

Table 5
Production and disposal of animal by-products in Greece [53]

Activity	Animal by-products (ton)
Production	267,951
Storage	2953
Incineration	151,188
Burial	88,293
Utilization as fertilizer or animal food	5558
Export	1445

The current process and disposal route of animal by-products is direct incineration, burial and/or landfill in 43 EC-approved landfilling sites that only accept pre-processed animal by-products. But, according to EC report, there is still a shortage of animal by-products destroying facilities and safe disposal is currently not ensured in Greece [53].

8. Economic aspects

Agricultural and animal waste management practice is very important for generating income and employment and could turn to be an economic way of energy production. Low-cost by-products of agriculture and animal breeding activity could enhance rural economies and keep them alive. This possibility seems to be more attractive when biomass is exploited under careful planning and in combination with a well-established energy production technology. But economic opportunities are viable and could play an important role, only under thoroughly inspected waste management practice and national motivation. With the rising fossil fuel prices, biomass conversion in energy will cost less in future and its utilization will contribute to money saving and environmental protection [47]. Rough topography of Greek rural areas gives biomass an extra cost that otherwise would not exist. *Decentralized or modular* form of bioenergy production would probably help those enterprises' economic viability. It could set free from labour cost, which is one of the main factors that make energy production from biomass quite expensive. Some economic data that affect energy production from biomass are depicted in Fig. 9. Biomass combined power generating systems are able to offer diminished costs and economic disengagement from fossil fuel dependence.

The lack of appropriate mechanization for biomass residue collection, the competitive markets (e.g. animal food industries), the big raw biomass volumes that must be transported, the lack of knowledge and inexistence in applicability of waste management are some of the factors that at the moment dominate in biomass negative exploitation for energy production reasons.

Currently there is no organized practice in agricultural and animal wastes management in Greece, and as a result their exploitation is still set aside due mainly to economic reasons

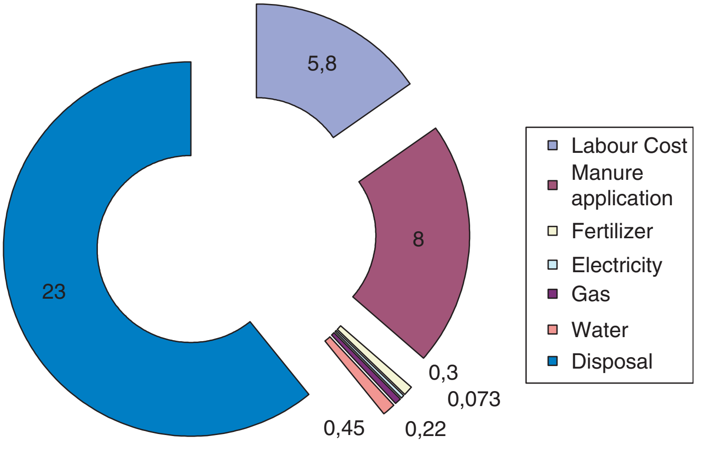


Fig. 9. Costs associated with energy production from biomass (€) [14].

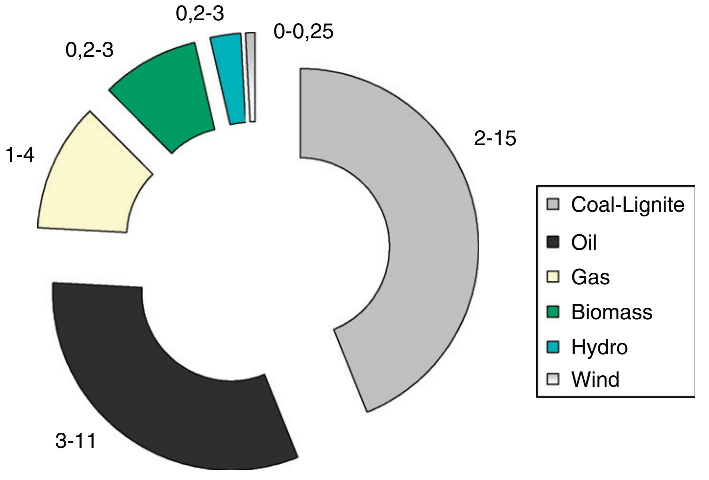


Fig. 10. Fuel costs associated with energy production (€) [10].

and lack of incentives for their efficient utilization, something that should not set aside the fact that biomass remains one of the cheapest fuel sources (Fig. 10). In Greece, at the moment, there is a considerable wood and wood by-product exploitation for energy production purposes, mainly by combustion technologies and only after private initiative. Some information about costs of biomass (mainly wood) combustion installations in proportion with installed capacity are shown in Table 6 [8].

But during the last decade, and under the pressures of EC Directive alignment with environmental protection targets, national commitments in reduction of greenhouse gases and biomass management instructions, there is a considerable interest in thermochemical technology (gasification and pyrolysis) application for energy and related material production from biomass resources.

9. Environmental impacts

Agricultural and animal wastes are able to contribute in a clean and safe renewable energy production and support country's socioeconomic development. Under sustainable conditions of exploitation, biomass could be a very promising alternative to fossil fuels and the old existing experience in thermochemical conversion techniques has already solved some technical problems.

Some of the benefits that agricultural and animal waste thermochemical treatment could offer are abatement in CO_2, NO_X, and SO_X emissions, preventing from phenomena like acid rain, smoke fog, and contribute to country's commitments in environmental protection. It is known that air pollution results in serious health problems and damages, thinns the ozone layer and leads to a climate change, but biomass conversion gases contribute positively to air pollution prevention and help in exhaust gas reduction. Biomass CO_2 content is the inherent—by photosynthesis—amount and natural decomposition would, otherwise, help it to return to environment. Additionally, it is known that methane from vegetable decomposition is much more active than released through thermochemical treatment, CO_2 [30]. Under this assumption, biomass thermochemical

Table 6
Classification and cost of biomass combustion installations in proportion with installed capacity [8]

Fuel	Combustor description	Fluid production	Cost during year 2000 (€)		
			1 MW	2 MW	3 MW
Sawdust (less than 21%ww moisture)	Ejection to the combustion chamber	Low pressure steam or hot water	70,433	88,041	105,649
Sawdust and wood chips (21–40%ww moisture, raw material, 20 mm size)	Filament combustion	-//-	73,368	105,649	126,192
Sawdust and wood chips (21–40%ww moisture, pre-dried material, 20 mm size)	Conduction of combustion gases through a rotary drier	-//-	102,715	146,735	176,082
Tree skin and wood chips mixture (max 40%ww moisture, pre-dried material, 20 mm size)	Filament charge				
0.6×10^{-6} Kcal/m^2 h	-//-	129,572	176,082	211,299	
Wood chips (300 mm)	Cybernated installation with combustion in steady filament	-//-	93,910	114,453	132,062
Heating of heat transfer oil (outlet temperature 280 °C)			4 MW	5 MW	6 MW
Cotton gin trash (3500 Kcal/kg)		Low pressure steam	410,858	410,858	484,226
Cotton gin trash (3500 Kcal/kg)		High pressure steam (10–12 bar)	n.a.	645,635	704,329

conversion techniques seem to be as attractive as natural decomposition, as it concerns the gaseous emission impact in atmosphere. Also, most of agricultural wastes have negligible sulphur content and, as a result, do not contribute to acid rain generation problem and SO_X releases to the atmosphere. Under strict combustion and thermochemical treatment control, problems like dioxin formation during animal wastes treatment is viable to be faced adequately [56,57].

Biomass utilization would also increase agricultural productivity, and ensure a better life standard for people living and working in rural areas. It would also help in ensuring reasonable prices for agricultural products, as the wastes from food products activity will gain an additional value. Agricultural and animal products would, in that way, become more competitive within and out of EU borders and help in environmental protection targets [41]. Farmers would have an incentive to use again that part of land which was not destined for agricultural and food production activities and would then treat their wastes properly.

Ash that biomass combustion produces is usually free of sulphur and for that reason is well applicable as fertilizer in farms. Co-combustion and co-gasification of coal and

biomass wastes fix annual availability, reduce its cost as a fuel and give better efficiencies. Sometimes biomass itself is cost-free and clearly does not depend on fuel price pressures. CH_4 and H_2 gases that formed could be used for heat and electricity production or burned in boiler.

As it concerns the socioeconomic impacts, biomass energetic exploitation could raise employment in rural regions and in that way contribute to urbanism prevention. Decentralized or modular form of biomass energy production could contribute to economic and social development of islands and distant regions.

Energy production of agricultural and animal wastes has a relatively low impact in local environment, including not only humans but also animals. As it concerns the current activities, under which agricultural/animal wastes management take place in Greece (left to decompose in soil or burning in fields), this practice hide some dangers. First of all, as it concerns the human health, there is a potential of lung-breathing illnesses, that are caused due to the smoke and gaseous emissions inhalation. The risk of uncontrolled fires is always on question, threatening the ecosystem, especially during the summer season and when temperatures are high and agricultural activities are in their peak. Additionally, burning those wastes always hide the danger or releasing some possibly dangerous chemicals that were absorbed from vegetable tissues, or consumed by animals. It introduces some risk in releasing heavy metals to the environment. Also, sound pollution can occur in some extent due to the machinery that is used for waste collection and management (tractors, trailers, etc.). Large amounts of wastes accumulated on field, mainly from animal wastes, create odour and aesthetic problems. Many pathogen bacteria are generated to animal manures and are carried in underground waters through manure leachates, attract vectors and impose serious odour emitting problem.

It should not also be underestimated the fact of the bad aesthetic of polluted areas, where huge amounts of biomass wastes (agricultural and/or animals) are left in open air to follow a natural decomposition route. Also, a possible danger would be the land degradation that could lead to severe flows during the winter rains, due to extensive harvesting. While, on the other side, over irrigation could lead to lack of water during summer or on the other side, leachates of those wastes could pollute water resources.

10. Conclusion

It is clear that Greece has a great opportunity to exploit its huge biomass stock, and specifically agricultural and animal wastes. Diverse topography and climate is a very important factor for country's energy autonomy and is of strategic importance. Under the recently set national commitments on EU legislations over environmental protection, alignment with Kyoto protocol emissions abatement and climate change protection, Greece could viably exploit its renewable energy sources, under an environmental friendly and economic viable way.

The future of biomass energy supply lies in the optimization of old-experienced techniques and combination through closed integrated cycles of energy production and exploitation. Greece is already making a very promising effort towards the satisfaction of EU environmental protection and renewable energy promotion policy targets, improving institutional, regulatory, research and funding changes favouring biomass utilization for energy purposes. Scientific research and international cooperation, under the assumption of law establishment and political enforcement through economic incentives in the field of

biomass energy exploitation, are going to strengthen the interest in agricultural and animal waste management, enforcing, also, the possibility of their expanded exploitation in energy production. Much effort focuses, the latest decade, on the benefits that thermochemical technologies are able to offer, not only in investigation but above all, in future technological application for alternative methods of exploitation of animal and agricultural waste potential in Greece.

Some weaknesses like the low repeatability, the high capital costs, huge biomass volumes that generated in rural areas could be solved through co-combustion/gasification of biomass and conventional fuels, decentralized and modular form of energy production systems and a very good established waste management/logistics system. But education, national legislation and research should shoulder the biggest part of the responsibility in disseminating the knowledge of biomass potential use in energy production systems.

The need in demonstration of innovative and state-of-the-art technologies for Greece's biomass waste exploitation is obvious. Reaching the target of high efficiencies, environmental-friendly technologies and integrated systems approach could be a viable solution to Greece's energy consumption demand and as a result its general socioeconomic development.

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References

[1] Anon. 2004. Greece Country Analysis Brief [online]. Available from: http://www.eia.doe.gov/emeu/cabs/greece.html [Accessed 17/6/2005].
[2] Earthtrends, Country Profiles; 2003. Energy and Resources-GREECE [online], Available from: http://earthtrends.wri.org [Accessed 7/72005].
[3] Hellenic Republic, Ministry of Development, Directorate General for Energy, Renewable Energy Sources and Energy Saving Directorate, 2003. National Report Regarding penetration level of Renewable Energy Sources in the year 2010 (Article 3 of Directive 2001/77/EC).
[4] Altener. ENER-IURE Project Phase II. Analysis of the legislation regarding Renewable Energy Sources in the E.U. Members States, Report concerning agriculture measures in Greece; 2002.
[5] Rosentrater KA. A review of corn masa processing residues: Generation, properties, and potential utilization. Waste Manage 2005;26(3):284–92.
[6] Anon. The Greek energy system. Public Electricity Corporation (PPC); 1998 [in Greek].
[7] Anon. European bioenergy networks. Eurobionet—biomass survey in Europe, Country report of Greece. Greece, 2003.
[8] Philippopoulos, N. Ach. Possibility of energetic exploitation of biomass and animal wastes. Unpublished work, 2005.
[9] Balat M. Use of biomass sources for energy in Turkey and a view to biomass potential. Biomass Bioenergy 2005;29:32–41.
[10] Vamvouka D, Zografos D. Predicting the behavior of ash from agricultural wastes using combustion. Fuel 2004;83(14–15):295–304.
[11] Scala F, Chirone R. Fluidized bed combustion of alternative solid fuels. Exp Therm Fluid Sci 2004;28:691–9.
[12] Deydier E, Guilet R, Sarda S, Sharrock P. Physical and chemical characterisation of crude meat and bone meal combustion residue: waste or raw material. J Hazard Mater 2005;121(1–3):141–8.
[13] Reijnders L, Huijbregts MAJ. Life cycle emissions of greenhouse gases associated with burning animal wastes in countries of the European Union. J Cleaner Product 2005;13(1):51–6.

[14] Abbas T, Awais Lockwood FC. An artificial intelligence treatment of devolatilization for pulverized coal and biomass in co-fired flames. Combust Flame 2003;132:305–18.
[15] Fernández A, Sánchez A, Font X. Anaerobic co-digestion of a simulated organic fraction of municipal solid wastes and fats of animal and vegetable origin. Biochem Eng J 2005;26(1):22–8.
[16] Khursheed K, Klasson T, Hoffmann R, Drescher SR, DePaoli DW, Al-Dahhan MH. Anaerobic digestion of animal waste: effect of mixing. Bioresour Technol 2005;96(16):1771–81.
[17] Gonzales JF, Encinar JM, Canito JL, Sabio E, Chacon M. Pyrolysis of Cherry stones: energy uses of the different fractions and kinetic study. J Anal Appl Pyrolysis 1995;67:165–90.
[18] Henihan M, O'Dywer TF, Sutton D, Leahy MJ. Advances in poultry litter disposal technologies-a review. Bioresour Technol 2002;83(1):27–36.
[19] Imbeah M. Composting of piggery waste: a review. Bioresour Technol 1998;63:197–203.
[20] Turner C. The thermal inactivation of *E. coli* in straw and pig manure. Bioresour Technol 2002;84:57–61.
[21] Ceotto E. The issues of energy and carbon cycle: new perspectives for assessing the environmental impact of animal waste utilization. Bioresour Technol 2005;96(2):191–6.
[22] Tsoutsos Th. Biofuels—environmental evaluation of their utilization and production, Oral Presentation in Greek 2005. Karditsa, Greece.
[23] Orecchini F, Bocci E. Biomass to hydrogen for the realization of closed cycles of energy resources. Third Dubrovnik conference on sustainable development of energy, water and environment systems, 5–10 June 2005. Dubrovnik, Croatia
[24] Bridgewater AV. The technical and economic feasibility of biomass gasification for power generation. Fuel 1995;74(5):631–53.
[25] Garcia-Ibanez P, Cabanillas A, Sanchez JM. Gasification of leached orujilo (olive oil waste) in a pilot plant circulating fluidized bed reactor. Preliminary results. Biomass Bioenergy 2004;27:183–94.
[26] Encinar JM, Beltran FJ, Ramiro A, Gonzalez JF. Pyrolysis/Gasification of agricultural residues by carbon dioxide in the presence of different additives: influence of variables. Fuel Process Technol 1998;55:219–33.
[27] Ozbay N, Putun AE, Uzun BB, Putun E. Biocrude from biomass: pyrolysis of cottonseed cake. Renew Energy 2001;24:615–25.
[28] McKendry P. Energy Production from biomass (part 3): gasification technologies. Bioresour Technol 2002;83:55–63.
[29] Avrelakis S, Koukios EG. Physicochemical upgrading of agroresidues as feedstocks for energy production via thermochemical conversion methods. Biomass Bioenergy 2002;22:331–48.
[30] Bridgwater AV. Renewable fuels and chemicals by thermal processing of biomass. Chem Eng J 2003;91:87–102.
[31] Conesa A, Fullana A, Font R. Dioxin production during the thermal treatment of meat and bone meal residues. Chemosphere 2005;59:85–90.
[32] Al-Marsi MR. Changes to biogas production due to different ratios of some animal and agricultural wastes. Bioresour Technol 2005;77:97–100.
[33] Osei E, Gassman PW, Hauck LM, Jones R, Beran L, Dyke PT, et al. Environmental benefits and economic costs of manure incorporation on dairy waste application fields. J Environ Manage 2003;68:1–11.
[34] Vamvouka D, Zografos D. Study of the influence of inorganic material in combustion of agricultural wastes from cultivations in Creta in fluidized bed conditions [In Greek].
[35] Zabaniotou A, Philippopoulos N, Koroneos C, Boura A, Moussiopoulos N. Technical, environmental, economical and energy analysis of alternative methods for the exploitation of agricultural wastes in Greece. First world conference on biomass for energy and industry. Sevilla, Spain, 2000.
[36] Zabaniotou A, Roussos A, Koroneos CJ. A laboratory study of cotton gin waste pyrolysis. J Anal Appl Pyrolysis 2000;56(1):47–59.
[37] Zabaniotou A, Karabelas AJ. The Evritania (Greece) demonstration plant of biomass pyrolysis. Biomass Bioenergy 1999;16(6):431–45.
[38] Zabaniotou A, Gogotsis D, Karabelas AJ. Product composition and kinetics of flash pyrolysis of Erica Arborea (biomass). J Anal Appl Pyrolysis 1994;29(1):73–87.
[39] Stavropoulos G, Zabaniotou A. Production and characterization of activated carbons from olive-seed waste residue. Microporous Mesoporous Mater 82(1–2): 79–85.
[40] Panoutsou SC. Biomass news, the newsletter of the European biomass association, research and technological developments on bioenergy in Greece. Available from: www.ecop.ucl.ac.be/aebiom/biomassnews/News9/Biomass9_1.htm [Accessed 5/7/2005].

[41] Luxemburg office for official publication on the European Communities, 2004, Energy transport and environmental indicators, Data 1991–2001.
[42] ECN-Biomass, energy research centre of Netherlands, Data Base Phyllis, Available from: http://www.ecn.nl/phyllis/dataTable.asp [Accessed 6/72005].
[43] Haapapuro ER, Barnard ND, Simon MD, M, JD, MPH. Review—animal waste used as livestock feed: dangers to human health. Prevent Med 1997;26:599–6002.
[44] Hill VR. Prospects for pathogen reductions in livestock wastewaters: a review. Crit Rev Environ Sci Technol 2003;30(2):187–235.
[45] Abelha P, Gulyurtlu I, Boavida D, Seabra Barros J, Cabrita I, Leahy J, et al. Combustion of poultry litter in a fluidized bed combustor. Fuel 2003;8:687–92.
[46] Kim HY. A low cost production of hydrogen from carbonaceous wastes. Int J Hydrogen Energy 2003;28:1179–86.
[47] Demirbas A. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. Progr Energy Combust Sci 2005;31:171–92.
[48] Mc Kendry P. Energy production from biomass (part 1): overview of biomass. Bioresour Technol 2002;83:37–46.
[49] Maniatis. Biomass and agriculture: sustainability, markets and policies, OECD Publication Service, EC, 2004. p. 317–34.
[50] National Center of Renewable Energy Sources.
[51] Review of the RAINS ammonia module, Country and emission category special data, Greece Whole Country, 10/12/98.
[52] Demirbas A. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Convers Manage 2001;42:1357–78.
[53] European Commission, Health & Consumer Protection Directorate-General, Directorate F-Food and Veterinary Office, Report of a mission carried out in Greece from 15 to 19 March 2004 concerning the disposal of certain animal by-products, DG (SANCO) /7015/2004-MR-Final.
[54] Regulation EC 1774/20002, MEMO/04/107, 6/5/2004, Questions and Answers on animal by-products, Available from: http://europa.eu.int/comm/food/fs/bse/legislation_en.html#by-products. Brussels [Accessed 8/7/2005].
[55] Europa-Rapid-Press-Releases, MEMO/01/378,20/11/2001,Commission services paper on the processing, disposal and uses of animal by-products in Member States. Brussels.
[56] Snowdon JA, Cliver DO, Converse JC. Land disposal of mixed human and animal wastes. Waste Manage Res 1989;17(2):121–34.
[57] Zhang FS, Yamasaki S, Nanzyo M. Waste ashes for use in agricultural production I. Limiting effect, contents of plant nutrients and chemical characteristics of some metals. Sci Total Environ 2002;284(1–3):215–25.